

REPORT DOCUMENTATION PAGE

AFRL-SR-AR-TR-02-

0442

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 11/25/02		3. REPORT TYPE AND DATES COVERED Final, March 15, 1997 - August 31, 2002	
4. TITLE AND SUBTITLE Learning Integrated Visual Database for Image Exploitation				5. FUNDING NUMBERS F49620-97-1-0184	
6. AUTHOR(S) Bir Bhanu					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Center for Research in Intelligent Systems Bourns College of Engineering University of California at Riverside Riverside, CA 92521-0425				8. PERFORMING ORGANIZATION REPORT NUMBER CRIS-AFOSR-RPT-02	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/DARPA Air Force Office of Scientific Research 4015 Wilson Blvd. Arlington, VA 22203-1954				10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release, distribution unlimited				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 Words) The research summarized in this report is aimed at developing image understanding (IU) algorithms and systems that have performance prediction and learning capabilities and that can improve their performance with experience, in terms of quality of results, processing speed and matching with the user's perception. The following scientific problems are addressed: (a) Fundamental theory for predicting the performance of object recognition systems and its validation on SAR images, (b) Automatic methods for recognizing articulated, occluded and configuration variants of targets in SAR images and video, (c) Adaptive learning integrated target recognition algorithms/systems, and (d) Learning visual concepts in images/videos with user interaction and experience over time. The research presented makes a significant contribution to real-world applications which require robust high performance automated systems that can recognize objects in reconnaissance imagery acquired under dynamically changing conditions and for systems that can efficiently extract meaningful information from enormous image/video databases.					
14. SUBJECT TERMS Target Recognition, Learning, Visual Databases.				15. NUMBER OF PAGES	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT unclassified	20. LIMITATION OF ABSTRACT none		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

20030509 091

Acknowledgements

We would like to thank Dr. Tom Strat (DARPA) and Dr. Abe Waksman (AFOSR) for getting this project started and their valuable comments and guidance. We want to thank Dr. Bob Herklotz (AFOSR) for his support and guidance at various junctures of this project. We also want to thank Dr. Clifford Rhoades, Jr. for his support when it was needed most. We want to thank Mr. Ed Zelnio (AFRL), Mr. Vince Velten (AFRL) and other DARPA and AFRL personnel for various important technical exchanges and discussions during the course of this project. Their help is greatly appreciated.

This final report describes the progress and accomplishments made on the project entitled, "Learning Integrated Visual Databases for Image Exploitation," during the period from March 15, 1997 to August 31, 2002.

1. OBJECTIVES:

The DoD has critical needs for robust high performance automated systems that can recognize objects in reconnaissance imagery acquired under dynamically changing conditions and for systems that can efficiently extract information from enormous image databases. Our research addresses two interrelated problems with the effectiveness and efficiency of automated/semi-automated techniques for image understanding. *First*, the lack of robustness in algorithms and systems for object recognition with changing environments and extended operating conditions. *Second*, the lack of scalable intelligent strategies for quickly extracting meaningful information from enormous, dynamically changing image databases. Our research is aimed at developing image understanding (IU) algorithms and systems that have performance prediction and learning capabilities and that can improve their performance with experience, in terms of quality of results, processing speed and matching with the user's perception.

The specific subgoals explored are:

Fundamental theory for predicting the performance of object recognition systems and its validation on SAR images,

Automatic methods for recognizing articulated, occluded and configuration variants of targets in SAR images and video,

Adaptive learning integrated target recognition algorithms/systems, and

Learning visual concepts in images/videos with user interaction and experience over time.

We have developed promising fundamental approaches and obtained excellent results to solve some of the crucial problems in image understanding and image databases that will have strong impact in solving real-world DoD applications. In the following we describe the major accomplishments achieved during the reporting period. Specific aspects of the research are given in greater detail in separate papers published in journals and major conferences. A list of all the published papers is also presented.

2. RESEARCH ACCOMPLISHMENTS

2.1 Recognition Performance Prediction and Fundamental Performance Bounds

We have developed fundamental techniques for predicting the performance of model-based object recognition systems in the presence of data uncertainty, occlusion and clutter. These techniques determine fundamental performance bounds (lower and upper) and set the limits on what is possible for a feature-based object recognition system. The new techniques capture the structural similarity between model objects, which is a fundamental factor in determining the recognition performance. We have done experiments to successfully *validate* the theory by comparing predicted PCR plots with ones that are obtained experimentally using MSTAR SAR data collected by AFRL for target recognition research under extended operating conditions.

In addition, we have developed SAR ATR algorithms that explicitly account for model similarity. In this work we optimize recognition models for SAR signatures of vehicles to improve the performance of a recognition algorithm under the extended operating conditions of target articulation, occlusion and configuration variants. The recognition models are based on quasi-invariant local features, scattering center locations and magnitudes. The approach determines the similarities and differences among the various vehicle models. Methods to penalize similar features or reward dissimilar features are used to increase the distinguishability of the recognition model instances. Extensive experimental results, in terms of confusion matrices and ROC curves, demonstrate the improvements in recognition performance for real SAR signatures of vehicle targets with articulation, configuration variants and occlusion.

Journal Publications:

1. M. Boshra and B. Bhanu, "Predicting performance of object recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No. 9, pp. 956-969, 2000.
2. M. Boshra and B. Bhanu, "Predicting an upper bound on SAR ATR performance," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 3, pp. 876-888, 2001.

3. B. Bhanu and G. Jones, "Increasing the discrimination of SAR recognition models," *Optical Engineering*, Vol. 41, No. 12, December 2002.

2.2 Automatic Target Recognition in Extended Operating Conditions ---- Articulated, Occluded and Configuration Variants of Targets

We have developed a model-based SAR recognition system that uses standard non-articulated models of objects to recognize the same objects in non-standard, occluded and articulated configurations. The system is based on the quasi-invariance of radar scatterer locations and magnitudes, while an accumulation of evidence from local features recognition approach successfully handles articulation, occlusion and configuration variants.

The independent views in SAR are an opportunity for increased recognition performance. The focus of this research has been to optimize the recognition of vehicles using multiple SAR recognizers. Both recognition from multiple look angles and multiple recognizers with different parameter tunings are investigated. Extensive experimental recognition results, in terms of receiver operating characteristic (ROC) curves, show the effects on recognition performance for MSTAR vehicle targets with articulation, configuration variants and occlusion.

Journal Publications

1. G. Jones and B. Bhanu, "Recognition of articulated and occluded objects," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 21, No. 7, pp. 603-613, 1999.
2. B. Bhanu and G. Jones, "Recognizing target variants and articulations in synthetic aperture radar images," *Optical Engineering*, Vol. 39, No. 3, pp. 712-723, 2000.
3. G. Jones and B. Bhanu, "Recognizing occluded objects in SAR images," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 1, pp. 316-328, 2001.

4. G. Jones and B. Bhanu, "Recognizing articulated targets in SAR images," *Pattern Recognition*, Vol. 34, No. 2, pp. 469-485, 2001.
5. J.S. Ahn and B. Bhanu, "Model-based recognition of articulated objects," *Pattern Recognition Letters*, Vol. 23, No. 8, pp. 1019-1029, 2002.
6. B. Bhanu and G. Jones III., "Multiple look angle SAR recognition," *International Journal of Imaging and Graphics*. Accepted.

2.2.1 Stochastic Models for Recognition

Recognition of occluded objects in synthetic aperture radar (SAR) images is a significant problem for automatic target recognition. Stochastic models provide some attractive features for pattern matching and recognition under partial occlusion and noise. We develop a hidden Markov modeling (HMM) based approach for recognizing objects in synthetic aperture radar (SAR) images. We identify the peculiar characteristics of SAR sensors and using these characteristics we develop feature based multiple models for a given SAR image of an object. The models exploiting the relative geometry of feature locations or the amplitude of SAR radar return are based on sequentialization of scattering centers extracted from SAR images. In order to improve performance we integrate these models synergistically using their probabilistic estimates for recognition of a particular target at a specific azimuth. Experimental results are presented using both synthetic and real SAR images.

Journal Publication

1. B. Bhanu and Y. Lin, "Stochastic models for recognition of occluded objects," *Pattern Recognition*, Revised September 2002.

2.2.2 Recognition of Human Articulated Motion

Current gait recognition approaches only consider individuals walking frontoparallel to the image plane. This makes them inapplicable for recognizing individuals walking from different angles with respect to the image plane. In this research, we develop a kinematic-

based approach to recognize individuals by gait. The new approach estimates 3D human walking parameters by performing a least squares fit of the 3D kinematic model to the 2D silhouette extracted from a monocular image sequence. A Genetic algorithm is used for feature selection from the estimated parameters, and the individuals are then recognized from the feature vectors using a nearest neighbor method. Experimental results show that the approach achieves good performance in recognizing individuals walking from different angles with respect to the image plane.

Reviewed Conference Publications

1. B. Bhanu and J. Han, "Individual recognition by kinematic-based gait analysis," *Proceedings International Conference on Pattern Recognition*, Vol. III, pp. 343-346, 2002.

2.2.3 Moving Shadow Detection

Moving object detection systems generally detect shadows cast by the moving object as part of the moving object. In this work the problem of separating moving cast shadows from the moving objects in outdoor environment is addressed. Unlike other previous work, we provide a method that does not use any geometrical information. Our physics-based approach is based on a new spatio-temporal albedo normalization test and a dichromatic reflection model. The physics based model is used both in the estimation and verification phases. We obtain results for several different video sequences representing a variety of materials and shadows. We achieve excellent results in distinguishing moving objects from their shadows. The results indicate that our approach is robust to a variety of background and foreground materials and varying illumination conditions.

Reviewed Conference Publications

- 1, S. Sohail and B. Bhanu, "Moving shadow detection using a physics-based approach," *Proceedings International Conference on Pattern Recognition*, Vol. II, pp. 701-704, 2002.

2.3 Adaptation and Learning for Target Recognition

We have developed several techniques based on reinforcement learning for closed-loop target recognition.

1. Reinforcement Learning:- team of learning automata: Current computer vision systems whose basic methodology is open loop or *filter* type typically use image segmentation followed by object recognition algorithms. These systems are not robust for most real-world applications. In contrast, the system presented here achieves robust performance by using reinforcement learning to induce a mapping from input images to corresponding segmentation parameters. This is accomplished by using the confidence level of model matching as a reinforcement signal for a *team of learning automata* to search for segmentation parameters during training. The use of the recognition algorithm as part of the evaluation function for image segmentation gives rise to significant improvement of the system performance by automatic generation of recognition strategies. The system is verified through experiments on sequences of indoor and outdoor color images with varying external conditions.

2. Delayed Reinforcement Learning: Object recognition is a multi-level process requiring a sequence of algorithms at low, intermediate and high levels. Generally, such systems are open loop with no feedback between levels and assuring their robustness is a key challenge in computer vision and pattern recognition research. A robust closed-loop system based on “delayed” reinforcement learning is introduced. The parameters of a multi-level system employed for model-based object recognition are learned. The method improves recognition results over time by using the output at the highest level as feedback for the learning system. Learning the parameters of image segmentation and feature extraction and thereby recognizing 2-D objects have experimentally validated it. The approach systematically controls feedback in a multi-level vision system and shows promise in approaching a long-standing problem in the field of computer vision and pattern recognition.

3. Use of Domain Knowledge in Reinforcement Learning: We have developed a general approach to image segmentation and object recognition that can adapt the image

segmentation algorithm parameters to the changing environmental conditions. Segmentation parameters are represented using a team of generalized stochastic learning automata and learned using connectionist reinforcement learning techniques. The edge-border coincidence measure is first used as reinforcement for segmentation evaluation to reduce computational expenses associated with model matching during the early stage of adaptation. This measure alone, however, cannot reliably predict the outcome of object recognition. Therefore, it is used in conjunction with model matching where the matching confidence is used as a reinforcement signal to provide optimal segmentation evaluation in a closed-loop object recognition system. The adaptation alternates between global and local segmentation processes in order to achieve optimal recognition performance. Results are presented for both indoor and outdoor color images where the performance improvement over time is shown for both image segmentation and object recognition.

4. Adaptive SAR ATR system based on Reinforcement Learning: Target recognition is a multi-level process requiring a sequence of algorithms at low, intermediate and high levels. Generally, such systems are open loop with no feedback between levels and assuring their performance at the given Probability of Correct Identification (PCI) and Probability of False Alarm (Pf) is a key challenge in computer vision and pattern recognition research. We have developed a robust closed-loop system for recognition of SAR images based on reinforcement learning. The parameters in model-based SAR target recognition are learned. The method meets performance specifications by using PCI and Pf as feedback for the learning system. Learning the parameters of the recognition system for SAR imagery has experimentally validated the approach, successfully recognizing articulated targets, targets of different configuration and targets at different depression angles.

5. Adaptive Recognition for Autonomous Navigation: Current machine perception techniques that typically use segmentation followed by object recognition lack the required robustness to cope with the large variety of situations encountered in real-world navigation. Many existing techniques are brittle in the sense that even minor changes in the expected task environment (e.g., different lighting conditions, geometrical distortion,

etc.) can severely degrade the performance of the system or even make it fail completely. We have developed a system that achieves robust performance by using local reinforcement learning to induce a highly adaptive mapping from input images to segmentation strategies for successful recognition. This is accomplished by using the confidence level of model matching as reinforcement to drive learning. Local reinforcement learning gives rises to better improvement in recognition performance. The system is verified through experiments on a large set of real images of traffic signs.

Journal Publications

1. J. Peng and B. Bhanu, "Closed loop object recognition using reinforcement learning," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 20, No. 2, pp. 139-154, 1998.
2. J. Peng and B. Bhanu, "Delayed reinforcement learning for adaptive image segmentation and feature extraction," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 28, No. 3, pp. 482-488, 1998.
3. B. Bhanu, Y. Lin, G. Jones and J. Peng, "Adaptive target recognition," *International Journal of Machine Vision and Applications*, Vol. 11, No. 6, pp. 289-299, 2000
4. J. Peng and B. Bhanu, "Learning to perceive objects for autonomous navigation," *Autonomous Robots*, Vol. 6, No. 2, pp. 187-201, 1999.
5. B. Bhanu and J. Peng, "Adaptive integrated image segmentation and object recognition," *IEEE Transactions on Systems, Man and Cybernetics- Part C*, Vol. 30, No. 4, pp. 427-441, 2000.
6. J. Peng and B. Bhanu, "Local discriminative learning for pattern Recognition," *Pattern Recognition*, Vol. 34, No. 1, pp. 139-150, 2001.

2.4 Learning Concepts in Images and Videos

We have developed two major ideas and approaches that relate low-level image features with high-level visual concepts in images to accomplish image based queries in large databases. The challenge has been to overcome the subjective nature of human image interpretation.

Key idea 1: Probabilistic Feature Relevance Learning for Content-Based Image Retrieval: Most of the current image retrieval systems use “one-shot” queries to a database to retrieve similar images. Typically a K-nearest neighbor kind of algorithm is used, where weights measuring feature importance along each input dimension remain fixed (or manually tweaked by the user), in the computation of a given similarity metric. However, the similarity does not vary with equal strength or in the same proportion in all directions in the feature space emanating from the query image. The manual adjustment of these weights is time consuming and it requires a very sophisticated user. We have developed a novel probabilistic method that enables image retrieval procedures to automatically capture feature relevance based on user’s feedback and that is highly adaptive to query locations. This feedback, in the form of accept or reject examples generated in response to a query image, is used to locally estimate the strength of features along each dimension while taking into consideration the correlation between features. This results in local neighborhoods that are constricted along feature dimensions that are most relevant, while elongated along less relevant ones. In addition to exploring and exploiting local principal information, the system seeks a global space for efficient independent feature analysis by combining such local information. We provide experimental results that demonstrate the efficacy of our technique using both simulated and real-world data.

Key Idea 2: Learning Visual Concepts: We have developed an approach for learning visual concepts in images based on statistical learning techniques for relevance feedback and fuzzy clustering. The fuzzy clustering technique successfully handles conditions where the concept features overlap. In this work, we address the problem of incorporating prior experience of the retrieval system to improve the performance on future queries. We develop a semi-supervised fuzzy clustering method to learn class

distribution (meta knowledge) in the sense of high-level concepts from retrieval experience. Using fuzzy rules, we incorporate the meta knowledge into a probabilistic relevance feedback approach to improve the retrieval performance. Results on synthetic and real databases show that our approach provides better retrieval precision compared to the case when no retrieval experience is used.

Journal Publications

1. J. Peng, B. Bhanu and S. Qing, "Probabilistic feature relevance learning for content-based image retrieval," *Computer Vision and Image Understanding*, Vol. 75, No. 1/2, pp. 150-164, 1999. (*Special Issue of Content-Based Access of Image and Video Libraries*)
2. J. Peng and B. Bhanu, "Independent feature analysis for image retrieval," *Pattern Recognition Letters*, Vol. 22, No. 1, pp. 63-74, 2001.
3. B. Bhanu and A. Dong, "Concept learning with fuzzy clustering and relevance feedback," *Engineering Applications of Artificial Intelligence*, Vol. 15, No. 2, pp. 123-138, 2002.

3. PERSONNEL SUPPORTED:

Bir Bhanu, Grinnell Jones, Jing Peng, Michael Boshra, Sohail Nadami, Jingchun Liu, Ju Han, Xuejun Tan, Yingqing Lin, Anlei Dong, Lynne Cochran, Daniel Morrione, Ping Liang, Jim Press, Daniel Rowe.

4. PUBLICATIONS (March 15, 1997 to 31 August 2002)

4.1 Journal Papers Published

- J. Peng and B. Bhanu, "Closed loop object recognition using reinforcement learning," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 20, No. 2, pp. 139-154, 1998.

- J. Peng and B. Bhanu, "Delayed reinforcement learning for adaptive image segmentation and feature extraction," *IEEE Transactions on Systems, Man and Cybernetics*, Vol. 28, No. 3, pp. 482-488, 1998.
- J. Peng and B. Bhanu, "Learning to perceive objects for autonomous navigation," *Autonomous Robots*, Vol. 6, No. 2, pp. 187-201, 1999.
- G. Jones and B. Bhanu, "Recognition of articulated and occluded objects," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 21, No. 7, pp. 603-613, 1999.
- J. Peng, B. Bhanu and S. Qing, "Probabilistic feature relevance learning for content-based image retrieval," *Computer Vision and Image Understanding*, Vol. 75, No. 1/2, pp. 150-164, 1999. (*Special Issue of Content-Based Access of Image and Video Libraries*)
- B. Bhanu and G. Jones, "Recognizing target variants and articulations in synthetic aperture radar images," *Optical Engineering*, Vol. 39, No. 3, pp. 712-723, 2000.
- B. Bhanu, I. Pavlidis and R. Hummel, "Guest Editorial, Computer vision beyond the visible spectrum," *International Journal of Machine Vision and Applications*, Vol. 11, No. 6, pp. 265-266, 2000.
- B. Bhanu, Y. Lin, G. Jones and J. Peng, "Adaptive target recognition," *International Journal of Machine Vision and Applications*, Vol. 11, No. 6, pp. 289-299, 2000.
- M. Boshra and B. Bhanu, "Predicting performance of object recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 22, No. 9, pp. 956-969, 2000.

- B. Bhanu and J. Peng, "Adaptive integrated image segmentation and object recognition," *IEEE Transactions on Systems, Man and Cybernetics- Part C*, Vol. 30, No. 4, pp. 427-441, 2000.
- J. Peng and B. Bhanu, "Local discriminative learning for pattern Recognition," *Pattern Recognition*, Vol. 34, No. 1, pp. 139-150, 2001.
- J. Peng and B. Bhanu, "Independent feature analysis for image retrieval," *Pattern Recognition Letters*, Vol. 22, No. 1, pp. 63-74, 2001.
- G. Jones and B. Bhanu, "Recognizing occluded objects in SAR images," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 1, pp. 316-328, 2001.
- G. Jones and B. Bhanu, "Recognizing articulated targets in SAR images," *Pattern Recognition*, Vol. 34, No. 2, pp. 469-485, 2001.
- M. Boshra and B. Bhanu, "Predicting an upper bound on SAR ATR performance," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, No. 3, pp. 876-888, 2001.
- J.S. Ahn and B. Bhanu, "Model-based recognition of articulated objects," *Pattern Recognition Letters*, Vol. 23, No. 8, pp. 1019-1029, 2002.
- B. Bhanu and A. Dong, "Concept learning with fuzzy clustering and relevance feedback," *Engineering Applications of Artificial Intelligence*, Vol. 15, No. 2, pp. 123-138, 2002.
- B. Bhanu and G. Jones, "Increasing the discrimination of SAR recognition models," *Optical Engineering*, Vol. 41, No. 12, December 2002. 27 pages.

- B. Bhanu and G. Jones III., "Multiple look angle SAR recognition," *International Journal of Imaging and Graphics*. Accepted.
- B. Bhanu and Y. Lin, "Stochastic models for recognition of occluded objects," *Pattern Recognition*, Revised September 2002.

4.2 Book Chapters

- J. Peng and B. Bhanu, "Pattern classification based on local learning," In *Advances in Pattern Recognition*, A. Amin, D. Dori, P. Pudil and H. Freeman, (Eds.), pp. 882-889, Springer, 1998.
- G. Sudhir and B. Bhanu, "Database-retrieval oriented approach for model-based object recognition," In *International Conference on Advances in Pattern Recognition*, S. Singh, (Ed.), pp. 23-32, Springer, 1999.
- J. Peng and B. Bhanu, "Independent feature analysis for image retrieval," In *Machine Learning and Data Mining in Pattern Recognition*, P. Perner and M. Petrou, (Eds.), pp. 103-115, Springer, 1999.
- G. Jones III. and B. Bhanu, "Recognition of articulated objects in SAR images," In *Articulated Motion and Deformable Objects*, H-H Nagel and F.J. Perales, (Eds.), Lopez, pp. 96-107, Springer, 2000.
- B. Bhanu and Y. Lin, "Stochastic models for recognition of occluded objects," In *Advances in Pattern Recognition*, F.J. Ferri, J.M. Inesta, A. Amin and P. Pudil, (Eds.), pp. 560-570, Springer, 2000.
- B. Bhanu and G. Jones, "Recognizing objects in SAR images," In *Image Recognition and Classification: Algorithms, Systems and Applications*, B. Javidi, (Ed.), pp. 61-100, Marcel Dekker, 2001

- B. Bhanu and A. Dong, "Concept learning with fuzzy clustering and relevance feedback," In *Machine Learning and Data Mining in Pattern Recognition*, P. Perner, (Ed.), pp. 102-116, Springer, July 2001.
- B. Bhanu and S. Fonder, "Learning-integrated interactive image segmentation," In *Theory and Application of Evolutionary Computation: Recent Trends*, A. Ghosh and S. Tsutsui, (Eds.), Springer, 2002.
- B. Bhanu and Y. Lin, "Recognition of occluded objects in SAR images," In *Pattern Recognition and String Matching*, D. Chen and X. Cheng, (Eds.), Kluwer Academic Publishers, 2002.

4.3 Edited Books/Special Issues of Journals

- B. Bhanu, I. Pavlidis and R. Hummel (Guest Editors), "Computer Vision Beyond the Visible Spectrum," *International Journal of Machine Vision and Applications* (Special Issue), Vol. 11, No. 6, pp. 265-329, May 2000.
- B. Bhanu and T. Boult, A. Gupta and D. Michael (Guest Editors), "Selected Papers from WACV 2000," *International Journal of Machine Vision and Applications* (Special Issue), Vol. 13, No. 3, pp. 109-184, 2002.
- B. Bhanu, J. Shen and T. Zhang (Editors), "Image Matching and Analysis," *SPIE Proceedings*, Vol. 4552, 354 pages, September 2001.
- T. Zhang, T., B. Bhanu and N. Shu (Editors), "Image Extraction, Segmentation and Recognition," *SPIE Proceedings*, Vol. 4550, 416 pages, September 2001.
- Pavlidis and B. Bhanu (Guest Editors), "Computer Vision Beyond the Visible Spectrum," *Image and Vision Computing* (Special Issue), 2002

4.4 CONFERENCE PAPERS PUBLISHED (All papers are fully reviewed)

- B. Bhanu and B. Tian, "Stochastic models for recognition of articulated objects," *Proceedings IEEE International Conference on Image Processing*, pp. 847-850, 1997.
- B. Bhanu and G. Jones, "Target recognition for articulated and occluded objects in synthetic aperture radar imagery," *Proceedings IEEE Radar Conference*, pp. 245-250, 1998.
- B. Bhanu and J. Peng, "Adaptive integrated image segmentation and object recognition," *Proceedings Eleventh Vision Interface Conference*, pp. 471-478, 1998.
- B. Bhanu, J. Peng and S. Qing, "Learning feature relevance and similarity metrics in image databases," *Proceedings IEEE Workshop on Content-Based Access of Image and Video Libraries*, pp. 14-18, 1998.
- J. Peng and B. Bhanu, "Learning to perceive for autonomous navigation in outdoor environments," *Proceedings IEEE Workshop on Perception for Mobile Agents*, pp. 95-104, 1998.
- J. Peng and B. Bhanu, "Local reinforcement learning for object recognition," *Proceedings International Conference on Pattern Recognition*, pp. 272-274, 1998.
- B. Bhanu and J. Ahn, "A system for model-based recognition of articulated objects," *Proceedings International Conference on Pattern Recognition*, pp. 1812-1815, 1998.
- B. Bhanu, S. Qing and J. Peng, "Learning integrated online indexing for image databases," *Proceedings IEEE International Conference on Image Processing*, pp. 789-793, 1998.

- M. Boshra and B. Bhanu, "Predicting object recognition performance under data uncertainty, occlusion and clutter," *Proceedings IEEE International Conference on Image Processing*, pp. 556-560, 1998.
- G. Jones and B. Bhanu, "Quasi-invariants for recognition of articulated and non-standard objects in SAR images," *Proceedings IEEE Workshop on Computer Vision Beyond the Visible Spectrum*, pp. 88-97, 1999.
- B. Bhanu, Y. Lin, G. Jones and J. Peng, "Adaptive target recognition," *Proceedings IEEE Workshop on Computer Vision Beyond the Visible Spectrum*, pp. 71-81, 1999.
- M. Boshra and B. Bhanu, "Performance prediction and validation for object recognition," *Proceedings IEEE Conference on Computer Vision and Pattern Recognition*, pp. 380-386, 1999.
- J. Peng and B. Bhanu, "Feature relevance estimation for image databases," *Proceedings Fifth International Workshop on Multimedia Information Systems (MIS'99)*, pp. 12-19, in *Advances in Multimedia Information Systems*, Edited by L. Golubchik and V.J. Tsotras, 1999.
- B. Bhanu and G. Jones III., "Object recognition results using MSTAR synthetic aperture radar data," *Proceedings IEEE Workshop on Computer Vision Beyond the Visible Spectrum*, pp. 55-62, 2000.
- B. Bhanu and Y. Lin, "Recognition of occluded objects using stochastic models," *Proceedings IEEE Workshop on Computer Vision Beyond the Visible Spectrum*, pp. 73-82, 2000.
- B. Bhanu and S. Fonder, "Learning based interactive image segmentation," *Proceedings International Conference on Pattern Recognition*, Vol. 1, pp. 299-302, 2000.

- S. Nadimi and B. Bhanu, "Multistrategy fusion using mixture model for moving object detection," *Proceedings International Conference on Multisensor Fusion and Integration for Intelligent Systems*, pp. 317-322, 2001.
- B. Bhanu and A. Dong, "Exploitation of meta knowledge for learning visual concepts," *IEEE Workshop on Content-based Access of Image and Video Libraries*, pp. 81-88, 2001.
- B. Bhanu, Y. Lin and S. Wang, "Feature selection for target detection in SAR images," *Proceedings IEEE Workshop on Computer Vision Beyond the Visible Spectrum*, 2001.
- S. Sohail and B. Bhanu, "Moving shadow detection using a physics-based approach," *Proceedings International Conference on Pattern Recognition*, Vol. II, pp. 701-704, 2002.
- J. Liu and B. Bhanu, "Learning semantic visual concepts from video," *Proceedings International Conference on Pattern Recognition*, Vol. II, 1061-1064, 2002.
- B. Bhanu and J. Han, "Individual recognition by kinematic-based gait analysis," *Proceedings International Conference on Pattern Recognition*, Vol. III, pp. 343-346, 2002.
- P. Yin, B. Bhanu, K. Chang and A. Dong, "Improving retrieval performance by long-term relevance information," *Proceedings International Conference on Pattern Recognition*, pp. Vol. III, pp. 533-536, 2002.
- X. Tan and B. Bhanu, "Robust Fingerprint Identification," *IEEE International Conference on Image Processing*, Vol. I, pp. 277-280, 2002.

4.5 DARPA Image Understanding Workshop Proceedings

- B. Bhanu, "Image understanding research at University of California, Riverside: Integrated recognition, learning and image databases," *Proceedings DARPA Image Understanding Workshop*, pp. 483-494, 1997.
- B. Bhanu, X. Bao and J. Peng, "Reinforcement learning integrated image segmentation and object recognition," *Proceedings DARPA Image Understanding Workshop*, pp. 1145-1154, 1997.
- B. Bhanu and B. Tian, "Multiple stochastic models for recognition of occluded targets in SAR images," *Proceedings DARPA Image Understanding Workshop*, pp. 1119-1128, 1997.
- G. Jones and B. Bhanu, "Invariants for the recognition of articulated and occluded objects in SAR images," *Proceedings DARPA Image Understanding Workshop*, pp. 1135-1144, 1997.
- J. Ahn and B. Bhanu, "Matching of articulated objects in SAR images," *Proceedings DARPA Image Understanding Workshop*, pp. 1167-1171, 1997.
- B. Bhanu, "Integrated recognition, learning and image databases: Image understanding research at University of California, Riverside," *Proceedings DARPA Image Understanding Workshop*, pp. 969-978, 1998.
- B. Bhanu, Y. Lin, G. Jones and J. Peng, "Adaptive target recognition using reinforcement learning," *Proceedings DARPA Image Understanding Workshop*, pp. 1177-1180, 1998.
- M. Boshra and B. Bhanu, "Bounding fundamental performance of feature-based object recognition," *Proceedings DARPA Image Understanding Workshop*, pp. 1155-1162, 1998.

- G. Jones III., B. Bhanu and J. Guo, "Geometrical and magnitude invariants for recognition of articulated and non-standard objects in MSTAR images," *Proceedings DARPA Image Understanding Workshop*, pp. 1163-1170, 1998.
- J. Peng, B. Bhanu and Y. Zeng, "Probabilistic feature relevance learning for online indexing," *Proceedings DARPA Image Understanding Workshop*, pp. 1171-1176, 1998.
- G. Sudhir and B. Bhanu, "Interactive target recognition using a database-retrieval oriented approach," *Proceedings DARPA Image Understanding Workshop*, pp. 1149-1154, 1998.

4.6 Conferences Organized by AFRL Personnel

- B. Bhanu and G. Jones, "Performance characterization of a model-based SAR target recognition system using invariants," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar IV*, 3070, pp. 305-321, 1997.
- B. Bhanu, G. Jones III. and J. Ahn, "Recognizing articulated objects and object articulation in SAR images," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery V*, Vol. 3370, pp. 493-505, 1998.
- M. Boshra and B. Bhanu, "Performance modeling of feature-based classification in SAR imagery," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery, V*, Vol. 3370, pp. 661-674, 1998.
- B. Bhanu and G. Jones, "Recognizing MSTAR target variants and articulations," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery VI*, Vol. 3721, pp. 507-519, 1999.

- M. Boshra and B. Bhanu, "Bounding SAR ATR performance based on model similarity," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery VI*, Vol. 3721, pp. 716-729, 1999.
- B. Bhanu and G. Jones III., "Recognizing occluded MSTAR targets," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery VII*, Vol. 4053, April 2000.
- M. Boshra and B. Bhanu, "Validation of SAR ATR performance predictions using learned distortion models," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery VII*, Vol. 4053, pp. 558-566, 2000.
- B. Bhanu and G. Jones III., "Increasing the discrimination of SAR recognition models," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery VIII*, Vol. 4382, pp. 308-317, 2001.
- B. Bhanu and G. Jones, "Exploiting azimuthal variance of scatterers for multiple look SAR recognition," *Proceedings SPIE Conference on Algorithms for Synthetic Aperture Radar Imagery IX*, Vol. 4727, pp. 290-298, 2002.